Fourth Annual Conference on
Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Geologic– Coal Seams (2)

Effects of Shrinkage and Swelling on Economics of Sequestration in Coal

Grant S. Bromhal, NETL/US DOE; Sinisha A. Jikich, NETL/Parsons
F. Burcu Gorucu, NETL/Penn State; W. Neal Sams, NETL/EG&G
Turgay Ertekin, Penn State; Duane H. Smith, NETL/US DOE

May 2-5, 2005, Hilton Alexandria Mark Center, Alexandria Virginia

US Climate Change Science Program www.climatescience.gov

Descriptor

Problem: How does inclusion of coal swelling change economic predictions for sequestration in Eastern coal seams?

- Eastern coal seams tend to be thin with high methane content and sequestration capacity per mass of coal and low water content relative to western coals.
- Shrinkage and swelling of coal in the presence of CO_2 is poorly understood, but some simple models have been developed.
- Some studies have been performed to consider the effects of coal material properties on sequestration capacity, but economics have not been included.

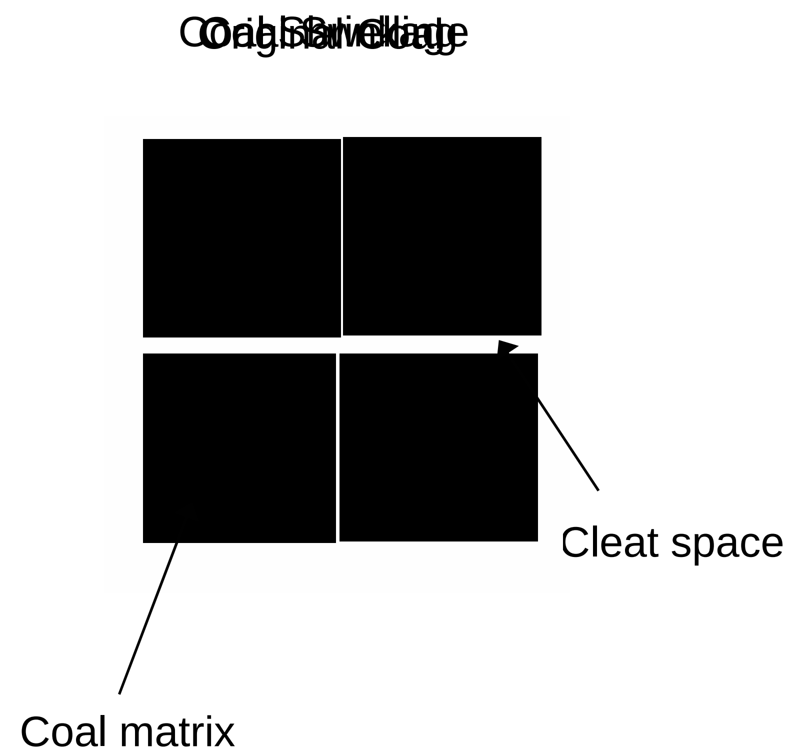
NETL

Approach: Economic analyses were based on coal seam simulations.

- Use PSU-COALCOMP, a state-of-the-art coalbed methane/sequestration simulator.
- Simulate sequestration in coal seams with a range of coal material properties (E,ν,ϕ).
- Collect start-up and operational cost data.
- Use “net present value” (NPV) analysis to compare multiple-year scenarios at different rates of return.

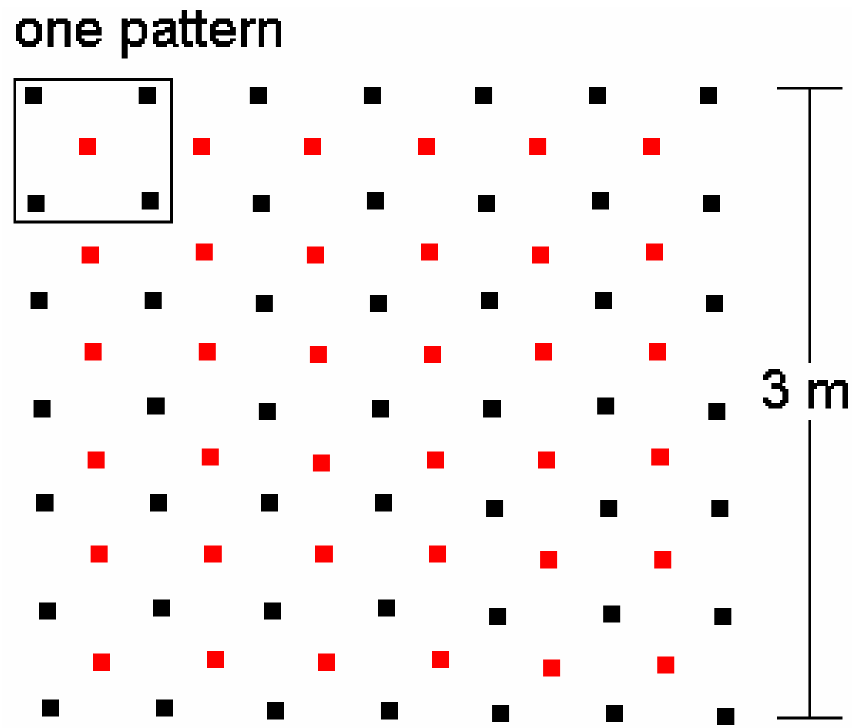
Coal shrinkage and swelling can have significant impact of cleat permeability.

- **Based on the Palmer-Mansoori model**
- **Most important effect is on permeability**
- **Most important coal properties for shrinkage and swelling:**
  - Porosity (ϕ)
  - Young's modulus (E)
  - Poisson's ratio (ν)



A 3-mile x 3-mile area with repeated well patterns was used for the purpose of scaling the economics.

- **Inverted five spot pattern, 160 acres**
- **Wells for single pattern:**
  - four producers (black squares)
  - one injector (red squares)
- **Wells needed for the repeated pattern:**
  - 49 producers
  - 36 injectors
- **Thirty-six full patterns to cover area**



Reservoir properties used are from Pittsburgh coal.

Reservoir Thickness	2m	Critical Gas Saturation	0.0 %
Depth	425 m	Critical Water Saturation	10.0%
Lateral Permeability	0.01 μm^2 (~10md)	Initial Water Saturation	40%
Skin	0.0	Reservoir Temperature	45^{o}C
Sorption Volume constant (CH_4, CO_2)	15 kg/tonne, 90 kg/tonne	Initial Mole Fraction of Gas (CH_4, CO_2)	100% 0%
Sorption Pressure constant (CH_4, CO_2)	5000 kPa, 2000 kPa	Reservoir Drainage Area	4.8 km x 4.8 km
Rock Density	1.4 g/cm^3	Wellbore Radius	0.1 m
Initial Reservoir Pressure	5000 kPa (~725 psi)	Coalface Pressure at Producers	700 kPa (~100psi)

Costs used were from industry and other available sources.

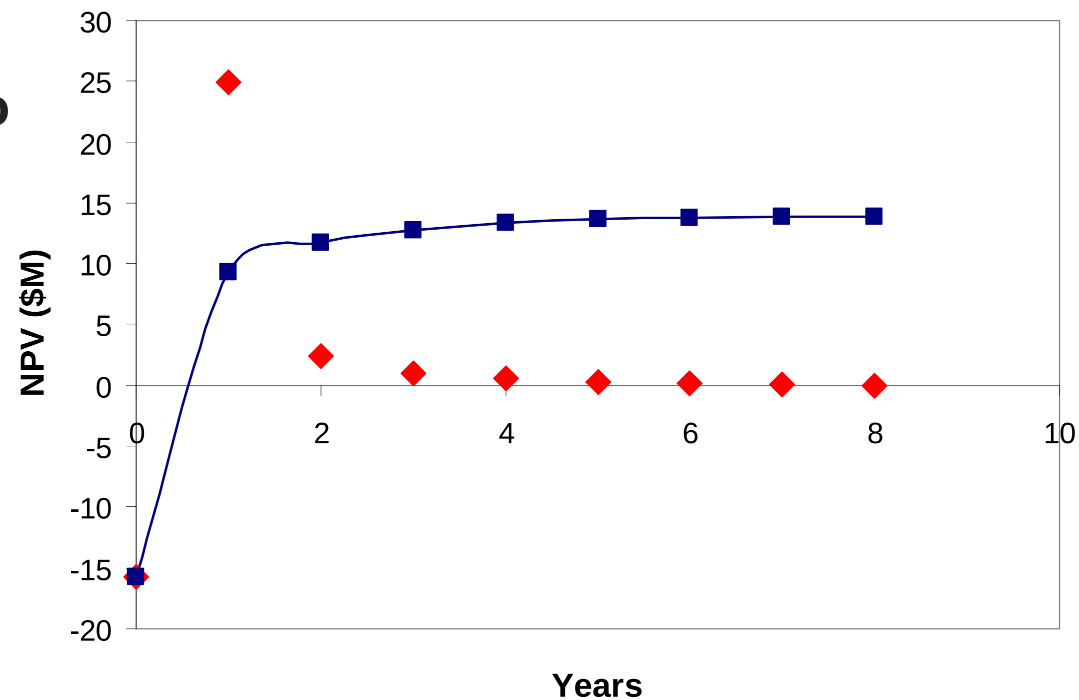
Cost Types		Amounts ($k)	
Start up	Drilling per well	94	
	Total for 85 wells		7,990
	Surface Equipment	19	
	Total for 85 wells		1,615
	Downhole Equipment	8	
	Total for 85 wells		680
	Pipeline costs 10 miles		150
	SMV capital costs (@10%)		1,045
Total Start-up			**11,480**
Yearly Costs	Operation and Maintenance		3,060
	SMV maintenance costs (@10%)		305
Total Yearly costs			**3,365**

Economic parameters	Price	
CH_4 price ($/mcf)	3 4 5	
CO_2 cost ($/tonne); ($/Mcf)	10 20 30 40 50	0.53 1.05 1.58 2.10 2.63
CO_2 credit ($/tonne); ($/Mcf)	0 5 10 15 20	0.0 0.26 0.53 0.79 1.05
Water Disposal Cost ($/STB)	0.40 0.99	
Interest Rate (%)	6 9 12 15 18	

Several economic parameters were varied.

Net present value (NPV) analysis was used for the economics.

- Each year, costs are subtracted from revenues.
- Profits are discounted to year zero (project start year) using given rate of return.
- NPV for all years is summed to give a single cumulative project NPV.
- NPV helps compare projects that have different dollar values in the future and different project lengths.



Red diamonds are yearly NPV values; blue line is cumulative NPV.

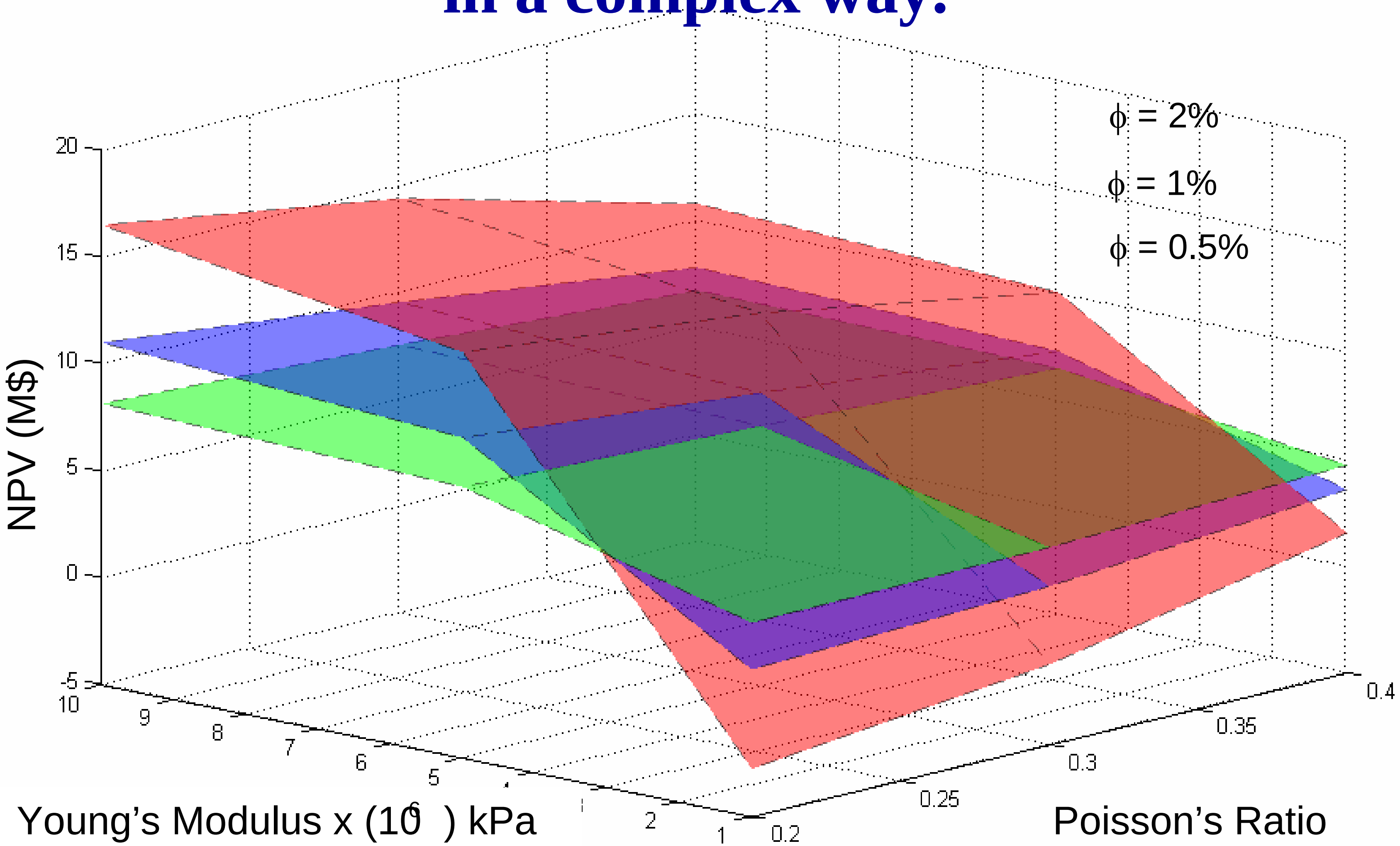
We performed sensitivity studies to determine the effects of coal seam properties (related to swelling) on project worth.

- **Coal parameters**
  - Young's modulus (E)
  - Porosity (ϕ)
  - Poisson's ratio (ν)

Young's Modulus ($\times 10^6$) Pa	Young's Modulus ($\times 10^6$) psi	Poisson's Ratio	Porosity (%)
1,000	0.145	0.2	0.5
5,000	0.725	0.3	1
10,000	1.450	0.4	2

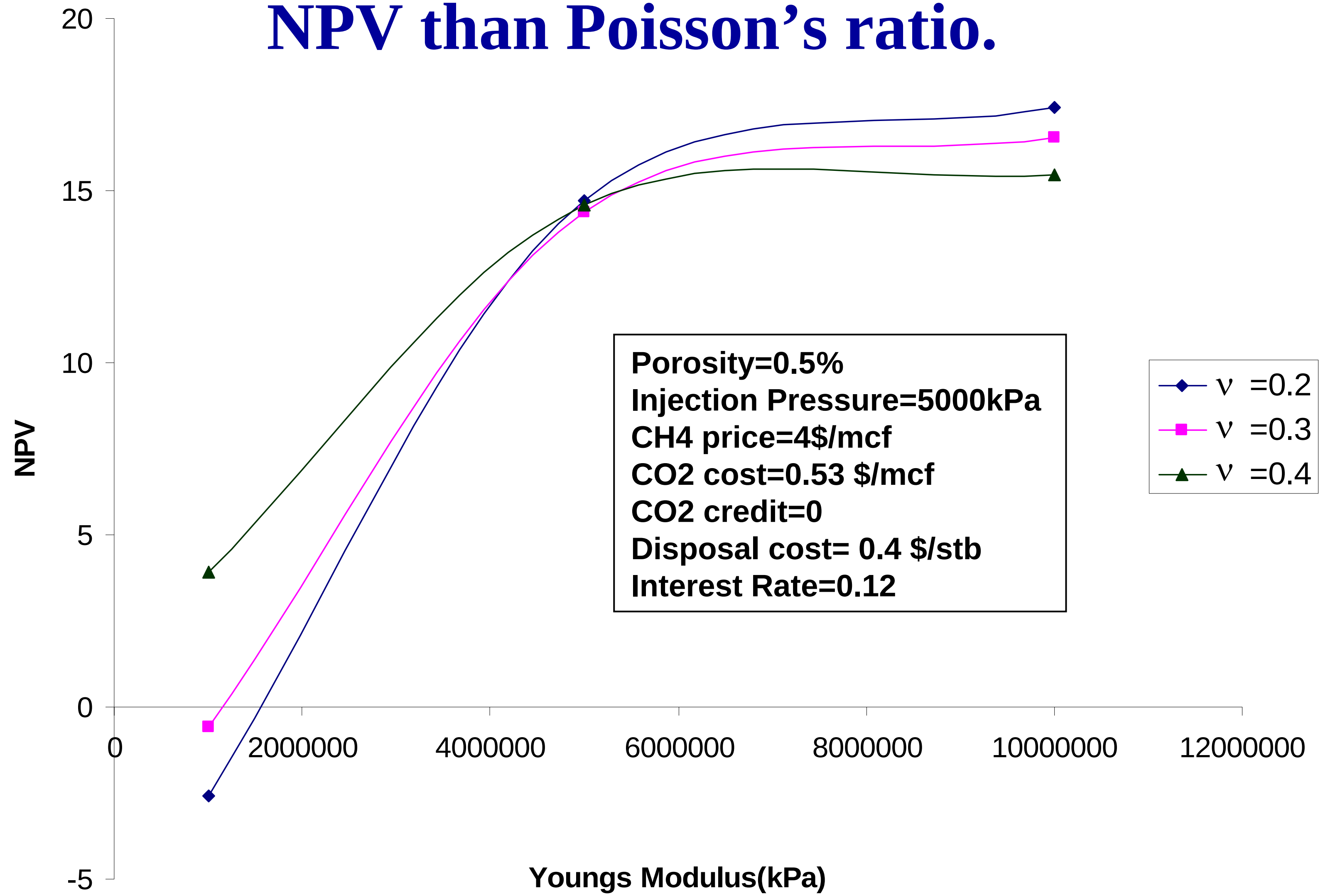
NETL

Net present value depends on the coal seam properties in a complex way.



For a fixed set of economic parameters, the NPV depends heavily on Young's modulus, Poisson's ratio, and porosity.

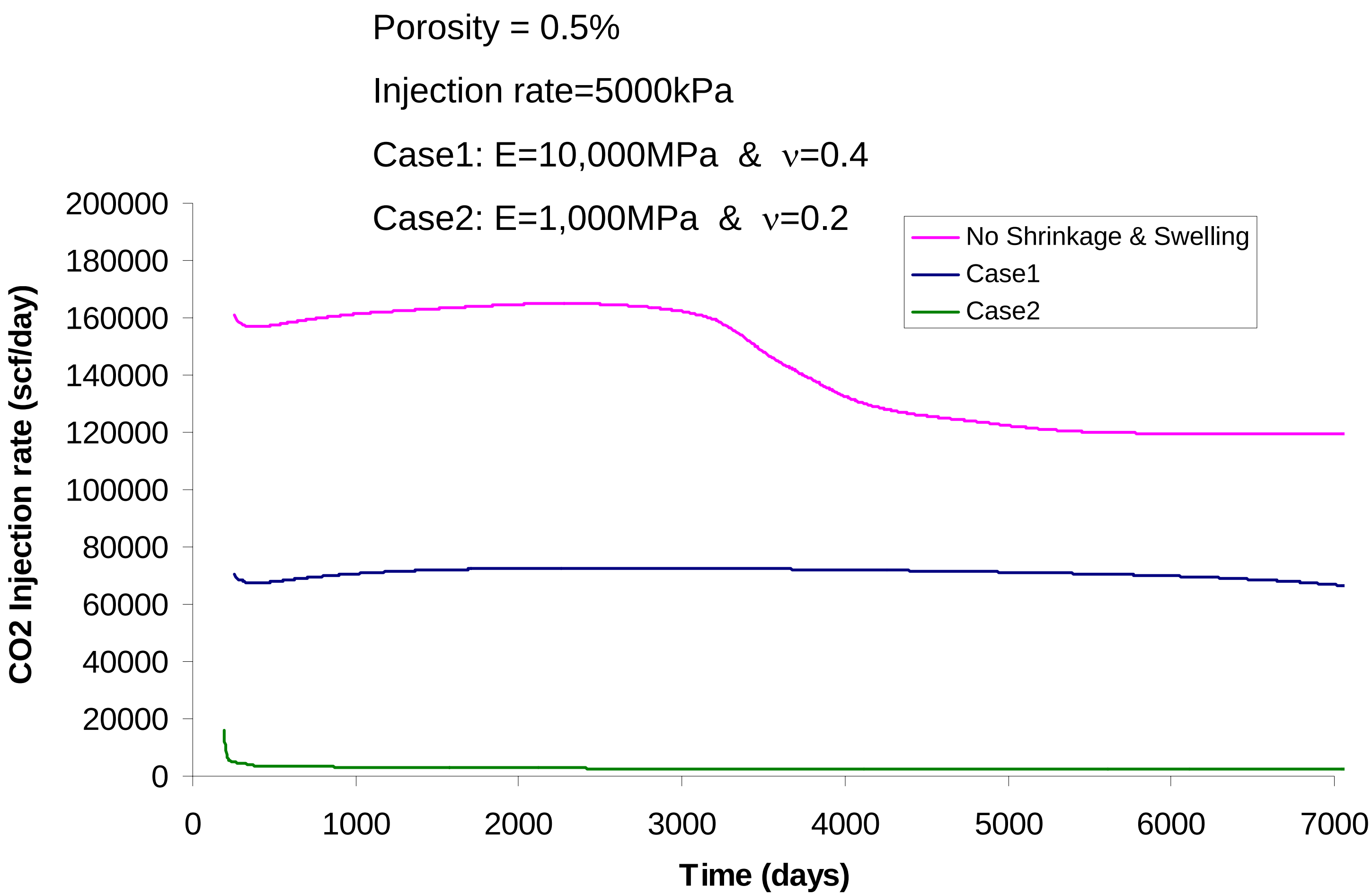
Young’s modulus has a much stronger effect on NPV than Poisson’s ratio.



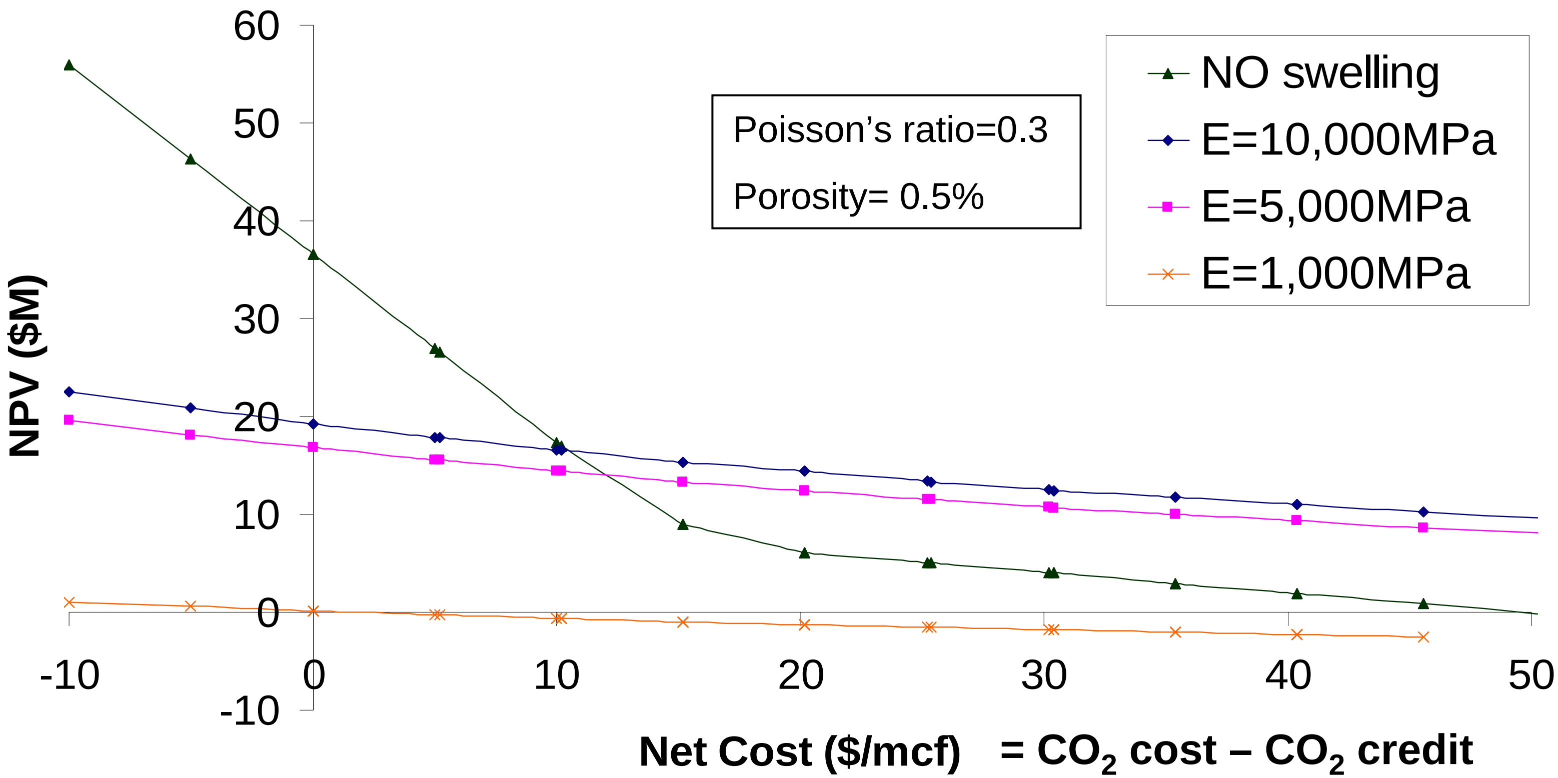
At low Young’s modulus, higher Poisson’s ratio give better results.

However, at high Young’s modulus, lower Poisson’s ratio give better results.

Swelling can significantly reduce injectivity.

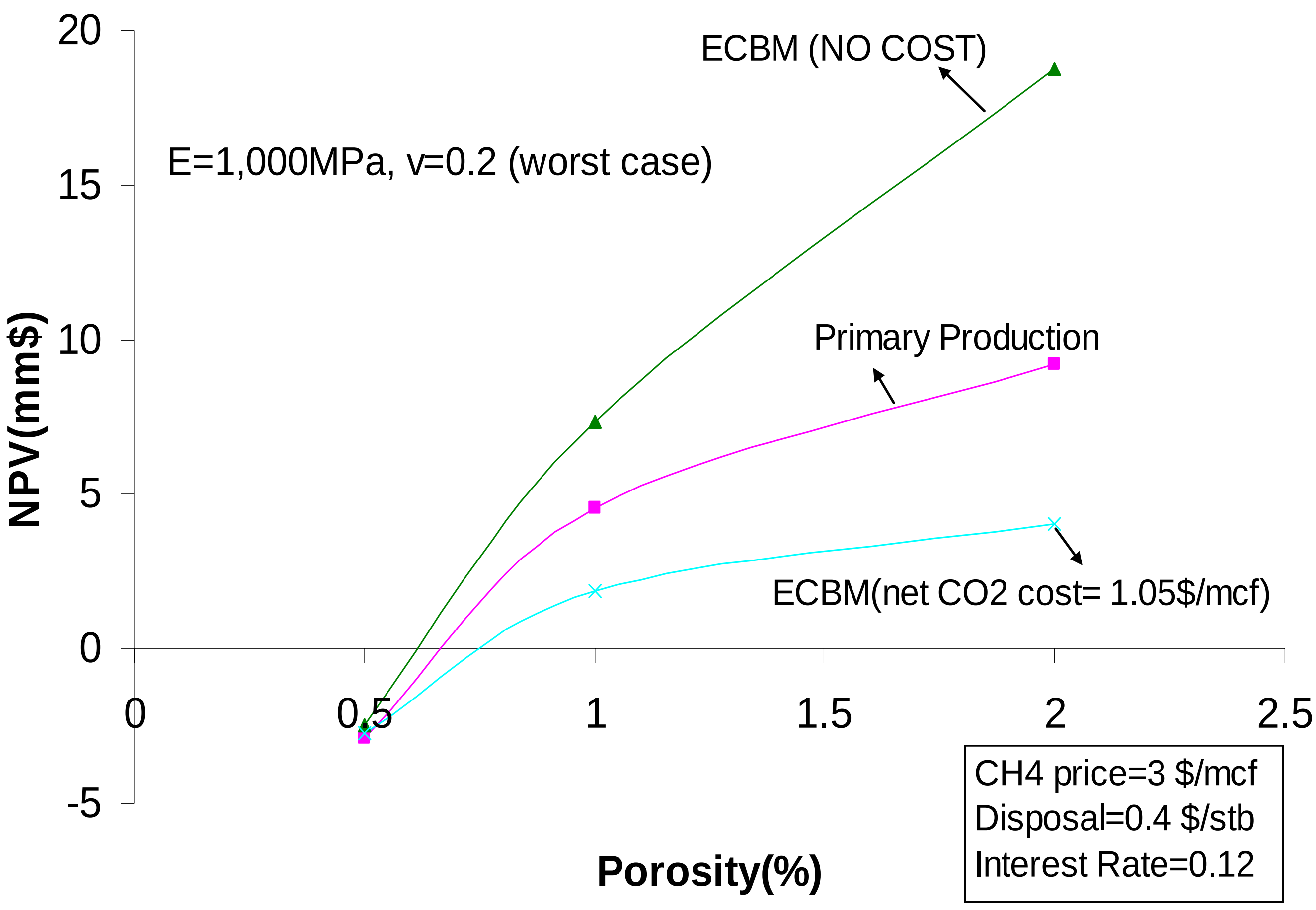


Swelling will have a significant impact on project worth.



- **At low CO_2 costs, neglecting swelling will lead to overestimating project worth.**
- **But at high CO_2 costs, neglecting swelling will lead to underestimating project worth.**

Porosity can have more impact than CO_2 cost.



- **CO_2 costs still have a significant effect for higher porosities.**

Conclusion: Shrinkage and swelling should be taken into account when planning coal seam sequestration.

- Injectivity of CO_2 decreases when swelling occurs.
- Cleat porosity and Young's modulus are critical parameters in determining a project's value.
- Profits from a project may be affected positively or negatively because of swelling.
- The net CO_2 cost will help determine if swelling contributes positively or negatively to NPV.

Other things to consider:

- Every coal seam is different!!!
- Multiple coal seams provide greater economic incentive.
- Different well patterns can be used to optimize sequestration.
- Injectivity may be increased by stimulating wells.
- Horizontal wells vs. vertical wells.
- Rising natural gas prices raise possibilities.
- Monte Carlo analysis may provide further insight.